WFIRST CGI Technology Testbeds Update

Fang Shi and Testbed Team

Mar 21, 2017

Outline

- **Testbed over view and plan**
- **Recent OMC testbed results**
  - Milestone 9
  - HLC wavefront control with 3 bandpass filters
  - Coronagraph contrast sensitivity to WFE
  - Testbed contrast drift
  - Focus correction residual contrast
- **Recent IFS/SPC testbed results**
- **Summary**

WFIRST CGI Technology Testbeds Overview

- **Milestone 9: successfully passed the MS9 follow up review on Jan 27**

- **Key milestones for FY 17 concentrate on flight like configurations and operations:**

Milestones	Milestone Date	Status	Comments
PISCES commissioning done. Calibration and data pipeline in place	12/31/2016	**Done**	In HCIT2
Close out Milestone 9.	1/31/2017	**Done**	Review slides cleared
HLC wavefront control with <=3 bandpass filters (# engineering filters for flight).	3/31/2017	**Done**	In HCIT1, 3 bandpass done and has reached ~4e-9
Demonstrate simultaneous EFC and LOWFS/C operation.	5/31/2017		In HCIT1
SPC wavefront control using PISCES IFS. 18% band high contrast.	5/31/2017	Started	In HCIT2,
Demonstrate SPC disc science mask performance with the imager, 6.5-20 l/D.	9/30/2017	Design finished	In HCIT2, design in progress
Low light (low SNR) OMC tests	12/31/2017		In HCIT1, current testbed drift investigation will be important for this task

Testbed Near Term Plan

- **To address the tall tent pole issues on the testbed results which are important to WFIRST CGI**
  1. Match the testbed results to testbed model: coronagraph contrast sensitivity
  2. Understand testbed Z4 residual and improve the DM correction loop performance
     - coronagraph contrast sensitivity
     - DM actuator gain calibration error
     - Testbed stability / drift: thermal / long DM actuator settling time
  3. Understand the testbed contrast stability and drift
     - Testbed thermal stability
     - DM actuator long settling time
  4. Match the testbed results to the design model
     - Use the design DM solution to improve the through put and improve the sensitivity
     - Match the tested sensitivity to the design model performance

WFIRST CGI Technology Testbeds Overview

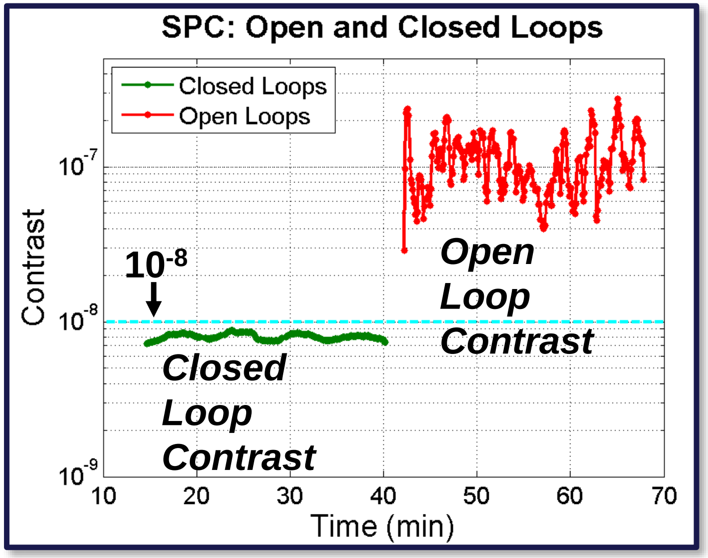
- **Generated, ranked, linked, and prioritized the testbed task list**
  - Technical development
  - CGI system engineering support
  - Operational efficiency improvement
- **Near term plan/activities on OMC testbed**
  - HLC EFC with 3 band filter
  - Understand and minimize post correct Z4 residual
    - Match Zernike WFE Sensitivity to testbed model and understand the discrepancy
  - Understand testbed coronagraph contrast drift
  - Improve throughput & sensitivity to match the design
- **Near term plan/activity on IFS/SPC testbed**
  - Prepare testbed HW & SW
  - EFC dark hole digging using IFS
  - Design / fab disk science SPC mask
- **Near term plan/activities on VSG testbed**
  - Finish TEMD task for Boston Micromachines DMs (end of March)
  - Understand and improve DM actuator gain calibration error
  - Investigate and test solutions for the DM actuator drift / long settling time issue

OMC Testbed Hit List

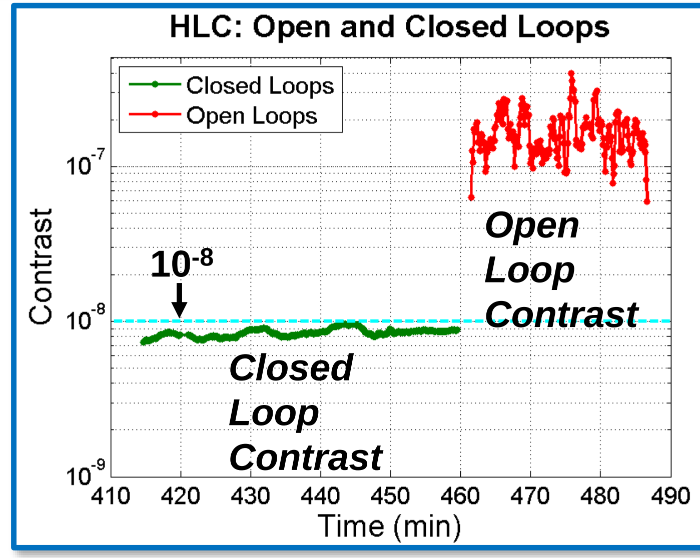
ID #	Task Description	Driven by	Priority (L/M/H)	Started? (Y/N)	Done? (N/IP/Y)	Comment & Result
T10	Redo SPC/HLC Zernike sensitivity calculations with best gainmaps available	I1	H	Y	IP	
T11	Make a decision on reverting to Option 2, and do the swap if necessary	T30	H	N	N	
T17	Come up with a test plan to determine what needs to be done to get the extent of the final DM gain model (1+ linear maps vs. per-actuator curve vs. full history model)	I2	H	N	N	
T20	Run focus-adjuster motion vs. source motion tests before OTA insertion	I2	H	Y	Y	
T21	Track down causes of Z4 residual and correct them	I2	H	N	N	
T23	Track down drifts on MCB prior to OTA insertion	I3	H	N	N	
T26	Get one of Dwight's low-jitter sensitivity DM solutions working on MCB	I1	H	N	N	
T30	Install back OTA-S	T11, T22, T23, T25	H	N	N	
T31	HLC LoS Jitter Sensivitity at mulitple planes	I2	H	Y	Y	SPC: email on 02/09/2017, HLC model/measurement mismatch
T34	Capture Pupil shear/magnification due to source/FA movmement	I2	H	Y	IP	
T37	Find the causes for 1/60 Hz signal in SPC LOWFS		H	Y	Y	
T38	Implement 120 Hz ringer for HLC	I4	H	N	N	
T39	Resolve the LoS loop crash issue		H	N	N	
T40	longe term drift on SPC mode	I3	H	N	N	
T02	Get both chambers recertified	T3	M	N	N	
T04	Wrap all HCIT lines or replace them with opaque tubing (or both) to prevent growth		M	N	N	
T12	Integrate and test Kalman filter module		M	N	N	
T16	Update dark frame calculation for Andors		M	N	N	
T19	Design and fabricate a mask of 1+ pinholes to go in the MCB FPM wheel		M	N	N	email on 02/08/2017
T22	Perform any desired tests with no obscuration while the opportunity exists (remove pupil obscuration, keep option-1 source head)	I2	M	N	N	
T24	Test Dwight's new mask (non-circularly-symmetric)	I5	M	N	N	
T25	Fix OTA-2 wire		M	N	N	email on 02/12/2017 (updated from 02/07/2017)
T27	Get access to main-bench thermal data		M	N	N	
T28	Set up training schedule for operators		M	N	N	
T29	Get phase retrieval working with seed electric-field (for non-flat starting points) as core functionality		M	N	N	Eric, Comment on this.
T33	Test "Jacobian compensation algorithm" in the testbed	T35	M	N	N	
T35	Speed up EFC convergence		M	N	N	
T36	Test no unprobing concept	T35	M	N	N	
T41	Flat WF LOWFS images using variours lowfs spots		M	N	N	
T42	Add more thermal sensors on: (1) DMs; (2) Cameras; (3) FSM	I3	M	N	N	
T43	diagnose and fix the STABLE box cross talks		M	N	N	
T01	Finish documenting core HCIT code (efc/, efc/util/, efc/config/func, ly/, ly/util/, extern/ functions used by testbed)		L	Y	N	
T03	Update HCIT-1 SOP to reflect vent/pump procedure		L	N	N	
T05	Rearrange EFC config to split into model and tbif parts		L	Y	N	
T06	Set up embedding of DMs in images		L	Y	N	
T07	Move Aerotech to rack on HCIT-1		L	N	N	
T08	Install new remote power strip and write control (as necessary)		L	N	N	email on 02/07/2017 from Joon
T09	Revive Jordan's watchdog software	T8, T13, T14	L	N	N	
T13	Install APC card in gullinbursti to monitor UPSes and import code from HCIT2 for this		L	N	N	
T14	Install second large UPS in MCB rack		L	N	N	
T15	Install turbopump on HCIT-1		L	Y	N	
T18	Put together a plan to flat-field Andor detectors (not necessarily in-situ) or a method to get data showing we don't need to (if we want to go that route)		L	N	N	

Summary of Milestone 9 Results

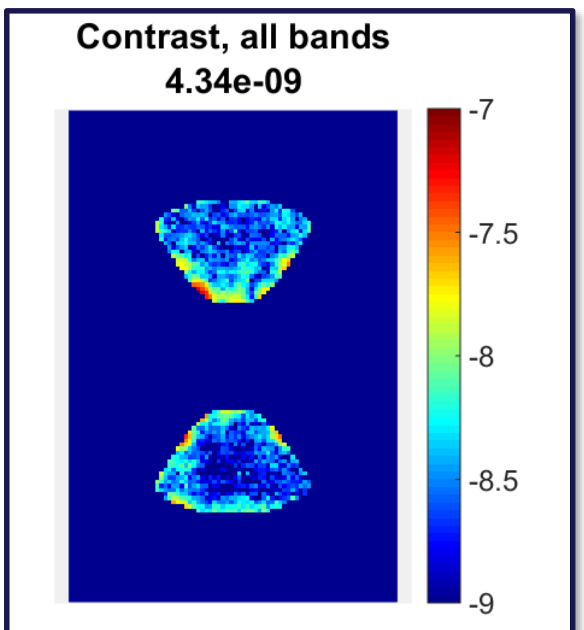
SPC Dynamic Test (10% at 550nm)



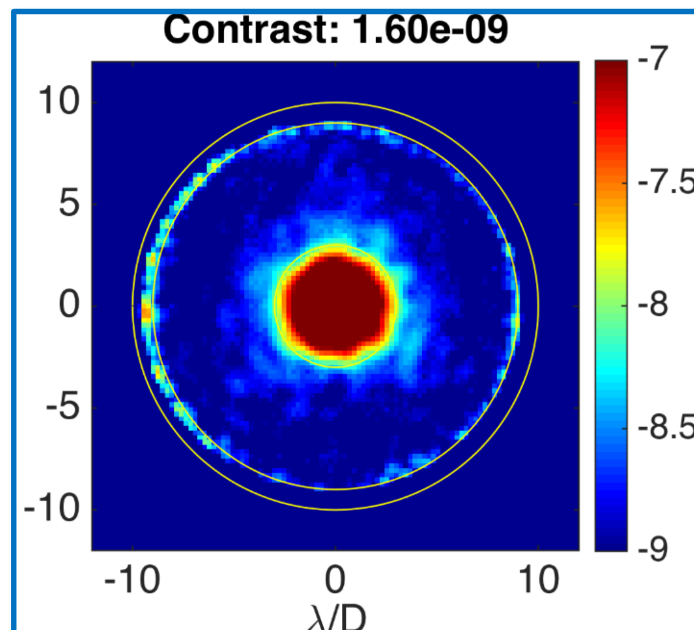
HLC Dynamic Test (10% at 550nm)



Best SPC Static Contrast (10% at 550nm)



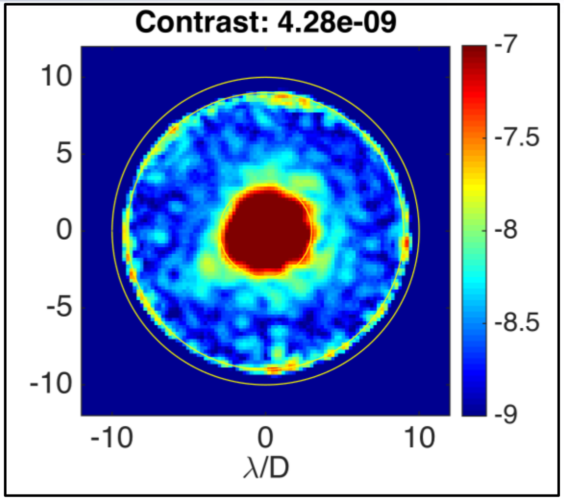
Best HLC Static Contrast (10% at 550nm)

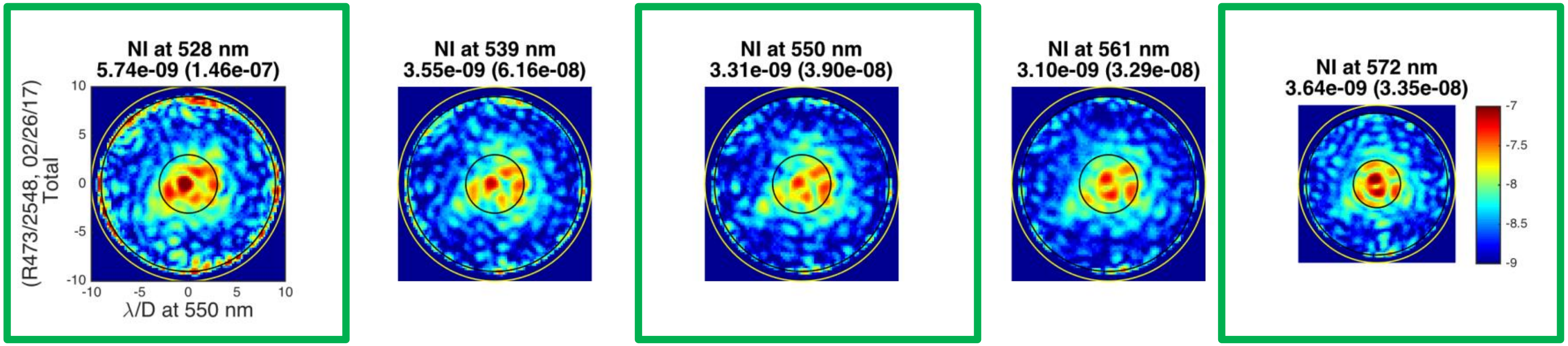


HLC EFC with Three Wavelength Bands

- **Test Configurations**
  - Three bands (528 nm, 550 nm, 572 nm) nulling
    - Note that current OMC HLC occulter is designed at 550 nm.
  - 4 % bandwidth (22 nm) for each band
    - More aggressive configuration than current engineering filter bandwidth of 3.3 %.
  - Initial DM solution for EFC: DM flat.
    - It is the most aggressive initial condition. This is to confirm EFC works even with this extreme condition.

10 % average at 550 nm





Control band

Control band

Control band

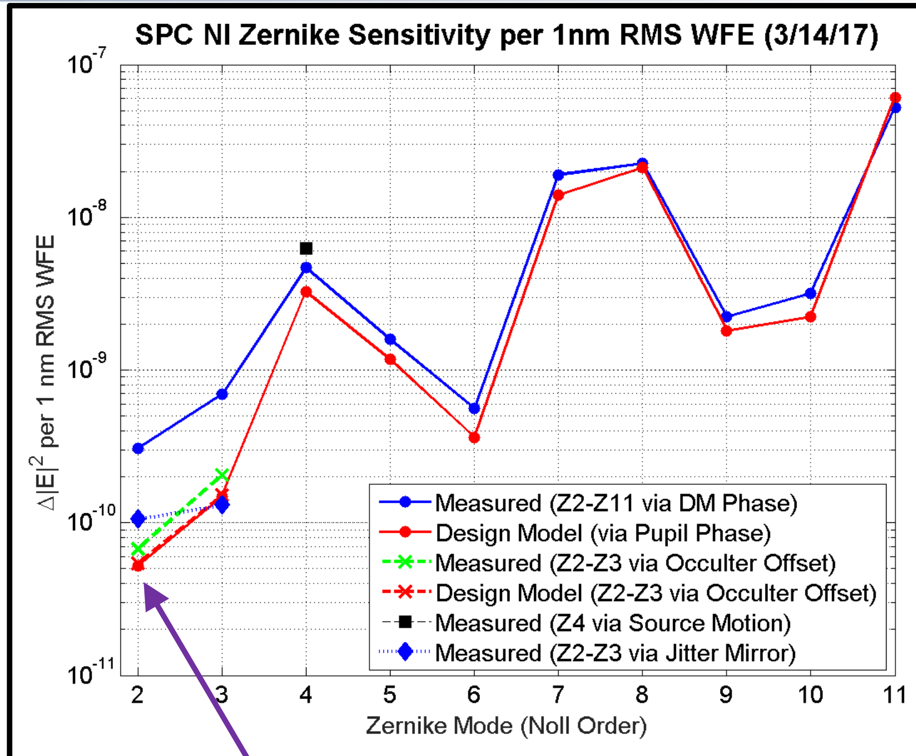
B-J. Seo

- **Results:**
  - Both the final 10 % contrast and its Zernike WFE sensitivity are consistent with those of normal 5 bands EFC.
  - Bandwidth of the bands does NOT affect the end-result if the bandwidth is 2% ~ 4 %.
  - Two-bands operation could NOT produce 5 band-consistent results.

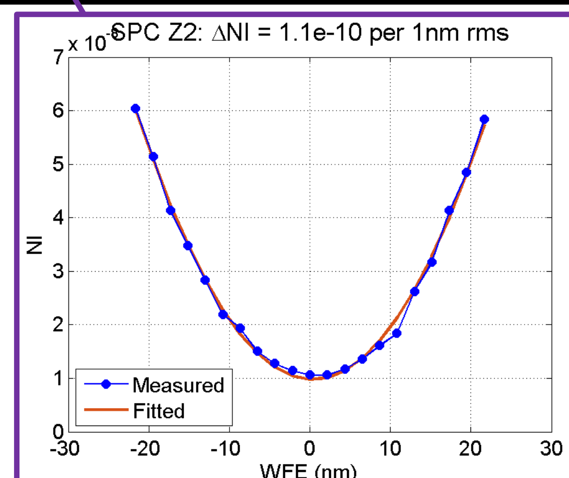
Contrast Sensitivity To WFE

Jet Propulsion Laboratory
California Institute of Technology

- **Understand the coronagraph contrast sensitivity to WFE modes**
- **Compare with model prediction**
  - Key component for coronagraph design, requirement, and science performance evaluation
- **Testbed tests (HLC and SPC):**
  - Start with a good coronagraph (NI< 1e-8)
  - Scan each WFE mode (Z2 – Z11) with varying amplitude
    - Multiple ways to generate Z2, Z3, Z4
    - Use DM2 for Z4 – Z11
  - Quadratic fitted coefficient (lower right) measures the contrast sensitivity to WFE (upper right)
- **The testbed data matches the model prediction well**
  - The large discrepancy from DM generated Z2 and Z3 is caused by DM actuator gain calibration error
  - HLC's match is not as good and test is on going



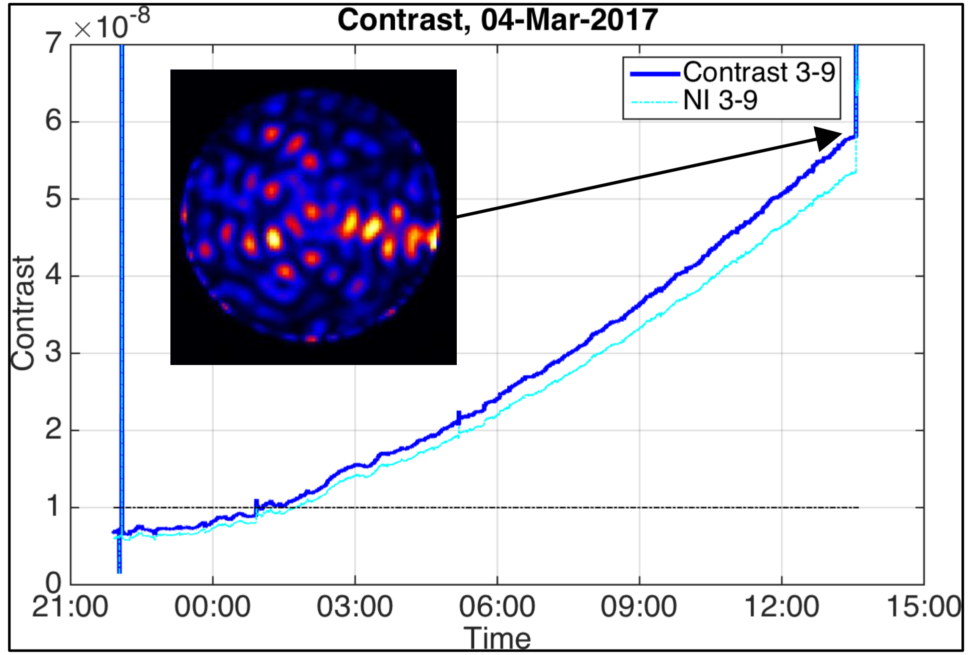
JM Injected Z2 Test



E. Cady

A ‘typical’ Dark Hole Drift

- **Test Configuration**
  - HLC mode
  - Just after EFC overnight
  - LOWFS LoS Closed-loop
    - FSM and JM strain gauge on
- **Test results:**
  - Even with LoS loop closed the coronagraph contrast degraded over the time
  - Morphology of the dark hole indicate the “drift” is not from low order WFE
  - Post drift EFC control shows that a few DM actuators motions are dominated the contrast degradation.
- **Diagnosis:**
  - **Some of DM actuators have a very long stroke settling time (hours) to a commanded voltage changes**



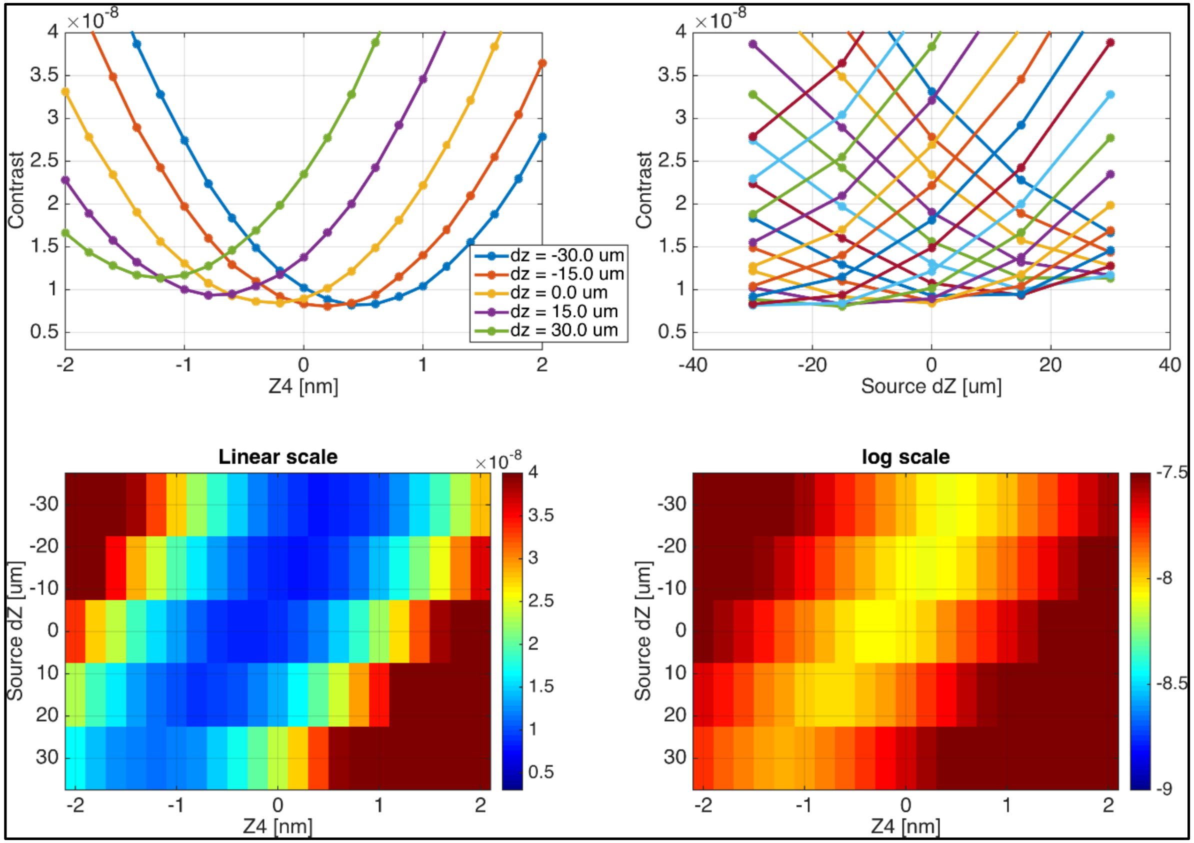
B-J. Seo

Understand Post Z4 Correction Contrast Residual

- **Test Configuration**
  - HLC contrast is measured while the wavefront focus (Z4) is scanned
  - Wavefront focus (Z4) are varied by (1) source Z motion and (2) DM #2 focus
    - Source Z motion generate true WF focus
  - LOWFS LoS Closed-loop to stabilize the line-of-sight drift

B-J. Seo

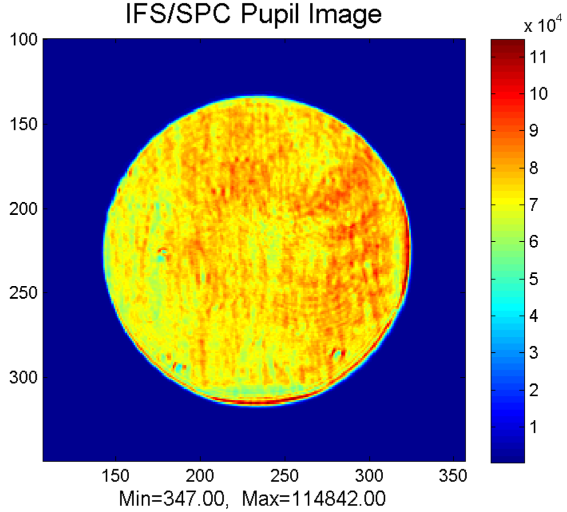
- **Test results**
  - The DM Z4 compensation does not perfectly recover the contrast degraded by source Z motion
  - Therefore the DM did not create a Z4 that perfectly matches the Z4 created by source Z motion
  - The imperfection of Z4 is caused by the DM actuator gain calibration error



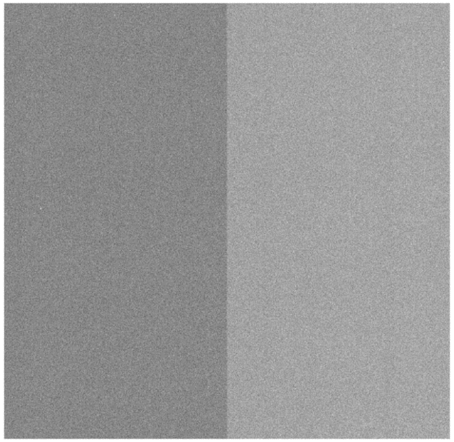
IFS/SPC Testbed: HW and SW Improvement

C. M. Prada

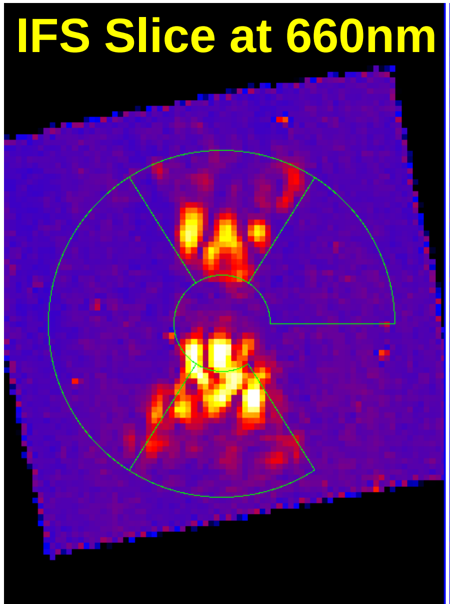
- **Pupil illumination uniformity improved with new MDL Pinhole**

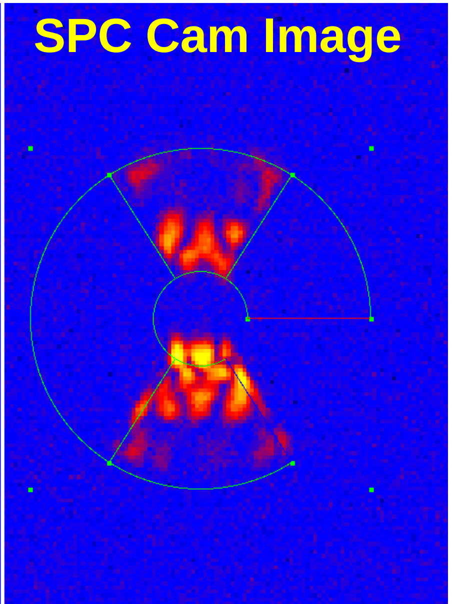


- **IFS dark image: stray light gone**



- **IFS data taken / process software stream lined**
- **EFC control (dark hole digging) with IFS has started**

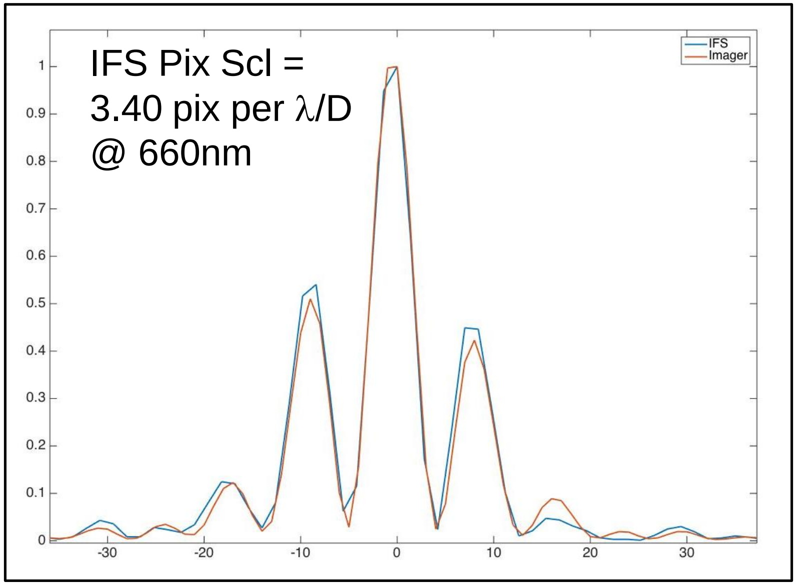




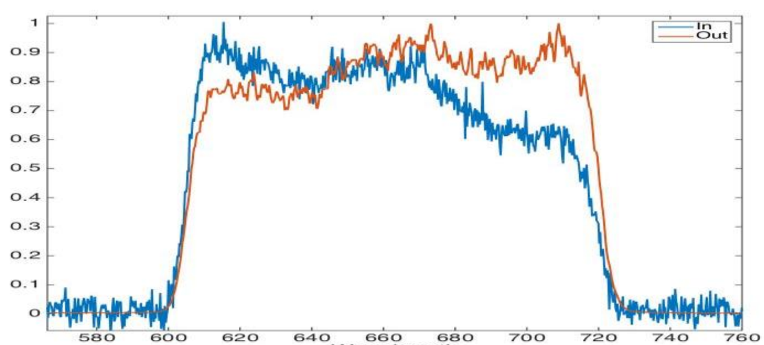
IFS/SPC Testbed: Calibrations

C. M. Prada

IFS Camera & SPC Imager Pixel Scale are Well Matched

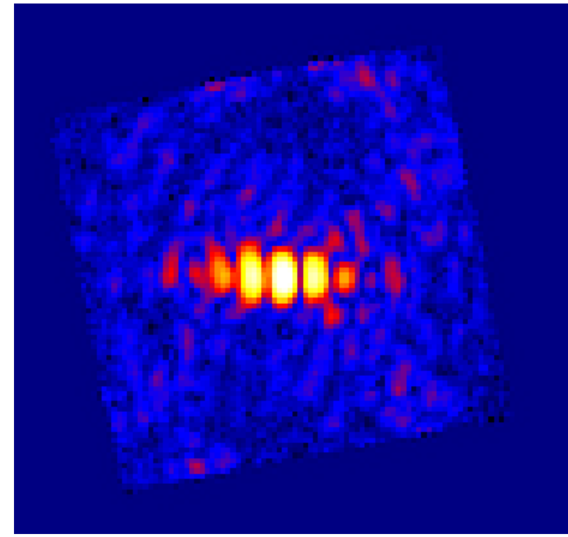


Source Spectral Calibration at IFS Entrance

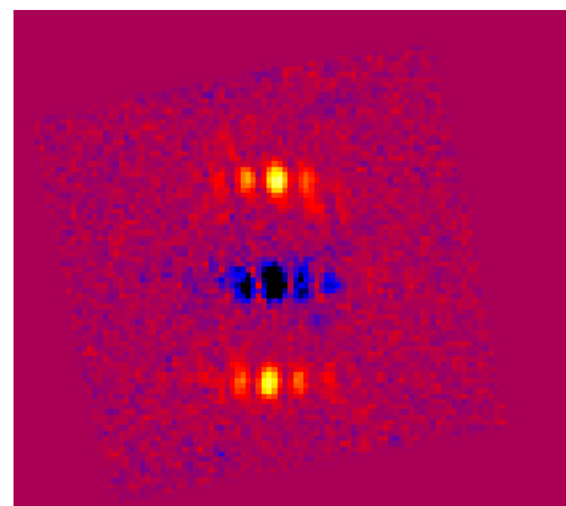


IFS Photometric Calibration

SPC PSF



DM Sine Poke at 6 λ/D



Summary and Future Work

- **WFIRST CGI technology testbeds continue to improve the CGI technology**
  - On track to meet the milestones for FY17
- **Testbed results and model verification provide key support to CGI system engineering**

Milestones in FY17

Milestones	Milestone Date	Status	Comments
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BACKUP

HLC Contrast Sensitivity to WFE

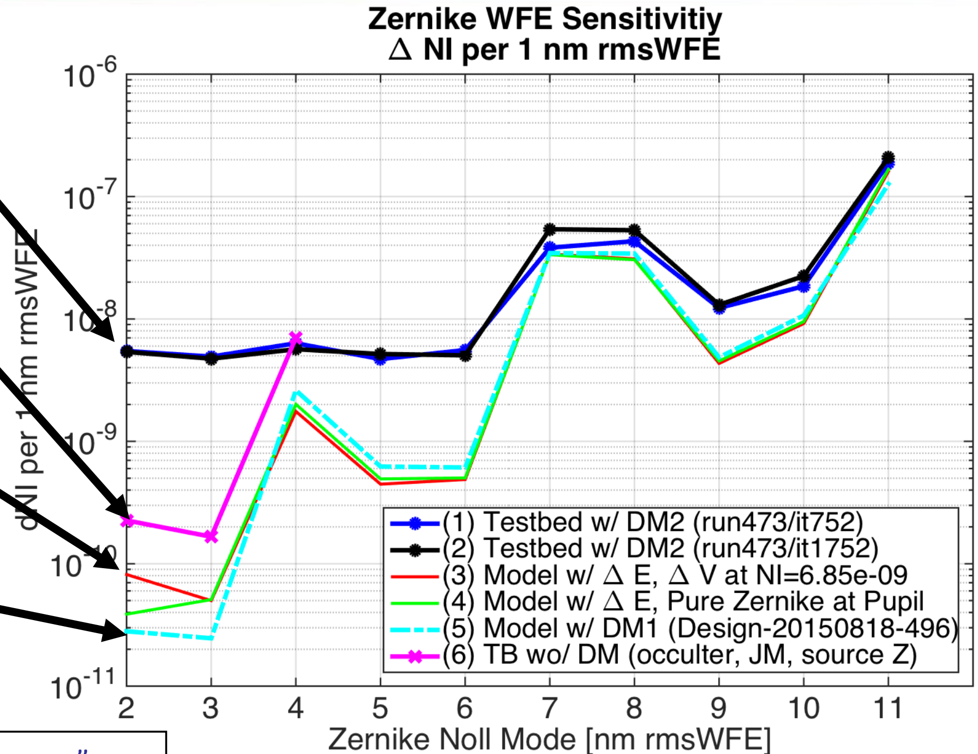
Jet Propulsion Laboratory
California Institute of Technology

(A) Testbed measurement using DM2

(B) Testbed measurement using NO DM (JM, occulter shift for Z2/3, Source Z for Z4)

(C) Control Model prediction

(D) Design Model prediction



Observation & Question

- P1 : Discrepancy between (A) and (B/C) is due to "DM-related errors" (gain or mis-registration, etc), which is estimated here about 5E-9 per 1 nm RMS. So, Z2,3,4 in (A) are dominated by this DM-related errors. This error seems spatially uncorrelated errors to introduced similar offset to Z2,3,4. ➔ AI1
- P2 : Discrepancy between (B) and (C/D) ➔ AI2
- P3 : Similar in (C) v.s (D) except Z2/3. Off-axis control difference? ➔AI2
- P4 : Jitter requirement using (B) should be a good/conservative value for budgeting purpose for now.
- P5 : "Eo issue" : Ctrl model Eo when Testbed has a good dark hole. Normally > 2E-4. ➔ AI3

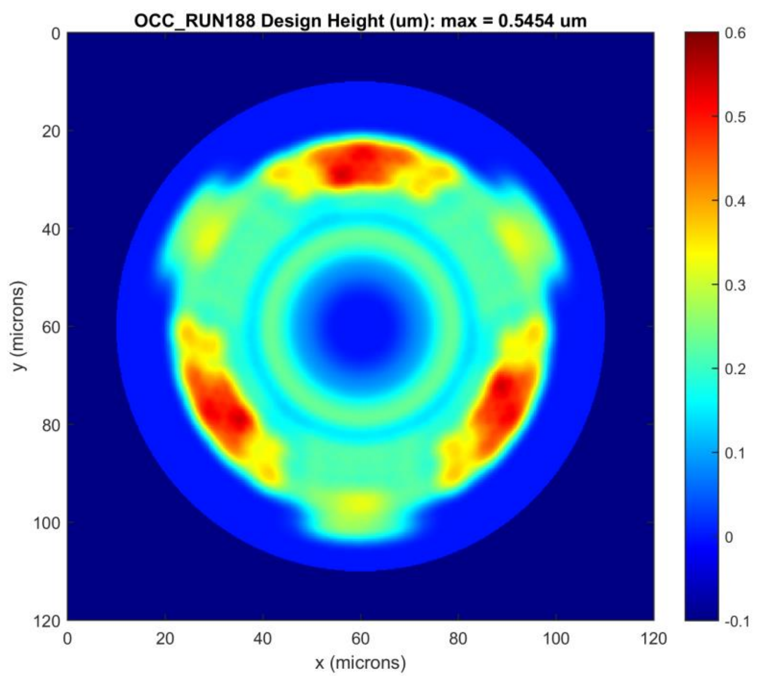
Action items

- AI1 : Understand Z4 residual using DM
- AI2 : Understand Design/Control model vs Testbed
- AI3 : Re-measure (B) with better dark hole.

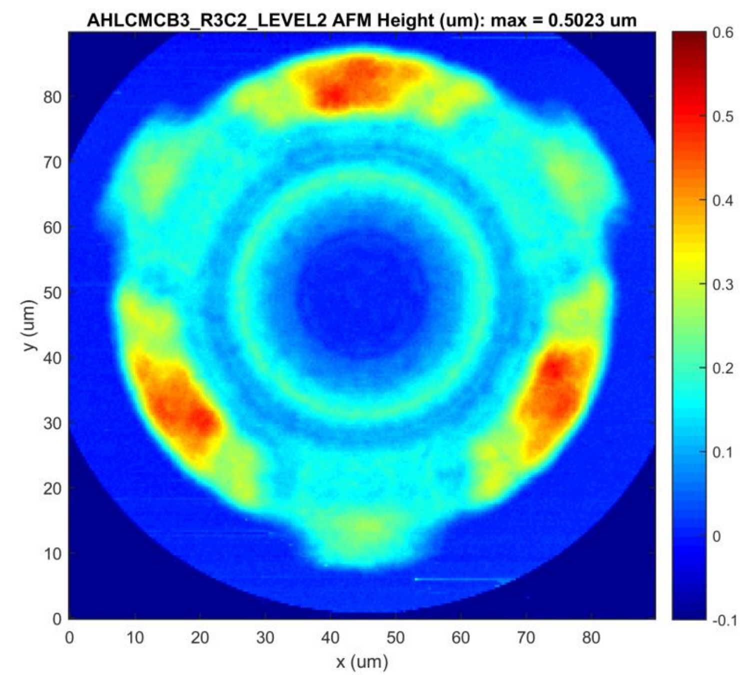
Comparison of Design and AFM of Fabricated Occulter

E-beam Jobs: AHLCNI18 + AHLCMCB3

Dwight Moody's 'Run188' Design



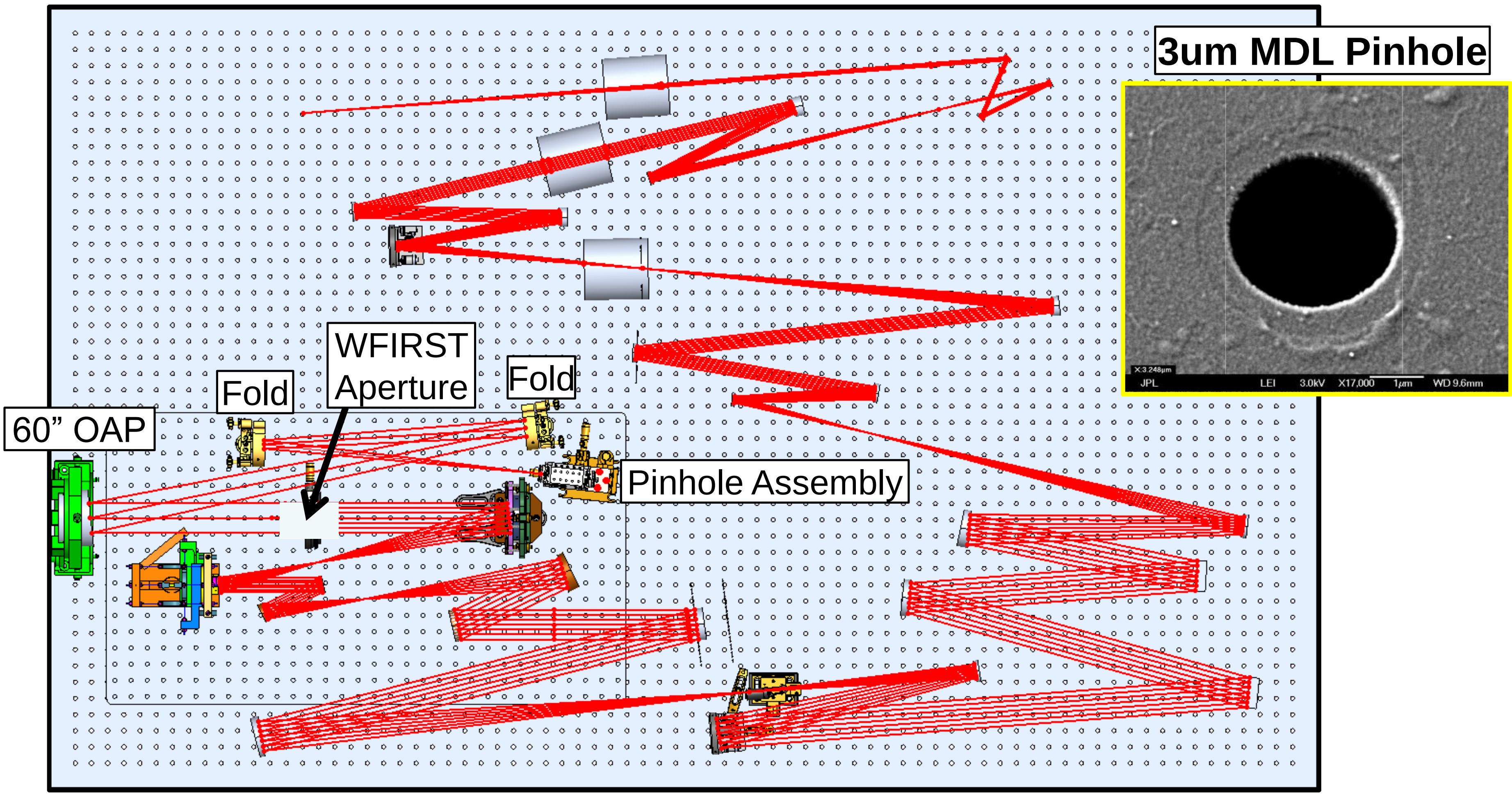
AFM of Row 3, Col 2 Occulter



- Plotted both with same color scale (set zero height at the top of the nickel dot to show dielectric thickness)
- Dielectric (PMGI resist) thickness error is about -8% based on max heights
- Profile looks generally faithful to the design (working on more detailed comparison) but resist is somewhat rough

Current Modified OTA Simulator: MS9

- F/33.3 injection with 60” OAP: significantly reduced (~5X) pseudo star size
- MDL pinhole: thin, non-metallic, etched in silicon at MDL, excellent dimension and edge
- Pinhole on a stage with a linear motor for focus disturbances.
  - Scale = 1 nm RMS focus / 32 um linear motor motion
- A freestanding pupil mask in collimated beam, replacing the OTA Telescope



Future Configuration

- Use a pair of OAP (30” and 6”) to relay the pinhole image to the focus of miniature WFIRST telescope: significantly reduced (~5X) pseudo star size
- MDL pinhole: thin, non-metallic, etched in silicon at MDL, excellent dimension and edge
- Keep the functionality of the original OTA Simulator but with the reduced pseudo star size